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Minahan et al.

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(54) **ENERGY-ABSORBING APPARATUS**

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B62D 21/15 (2006.01)

(52) **U.S. Cl.**
CPC ***B62D 21/152*** (2013.01)

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CPC F01D 25/24; Y02T 50/971; Y02T 10/126; B64C 2027/002; B64C 27/001; E01C 21/00; G11B 23/087; B65D 77/006; E05Y 2900/20; F02M 31/135
USPC 296/187.09
See application file for complete search history.

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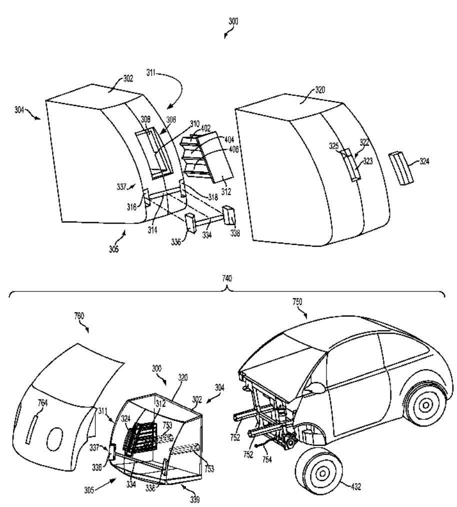
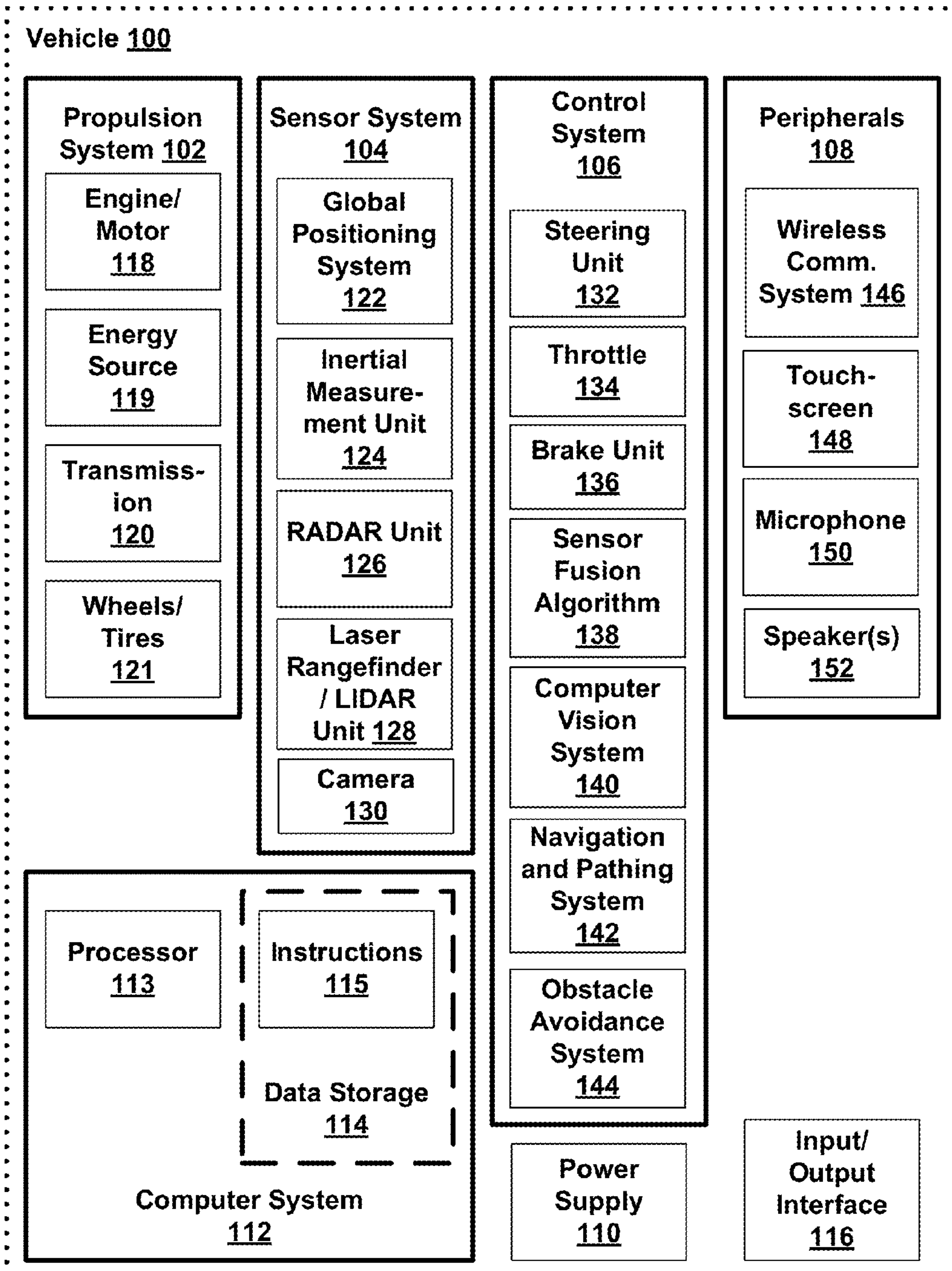
(57) **ABSTRACT**

In one example, an apparatus includes a casing configured to be coupled to a frame of a vehicle at a first end of the casing. The casing comprises friable foam having a first stiffness. The apparatus further includes a void within the casing defined by (i) an inner wall of the casing and (ii) an opening at a second end of the casing. The apparatus further includes an insert positioned within the void, the insert comprising a material having a second stiffness that is different from the first stiffness.

11 Claims, 8 Drawing Sheets

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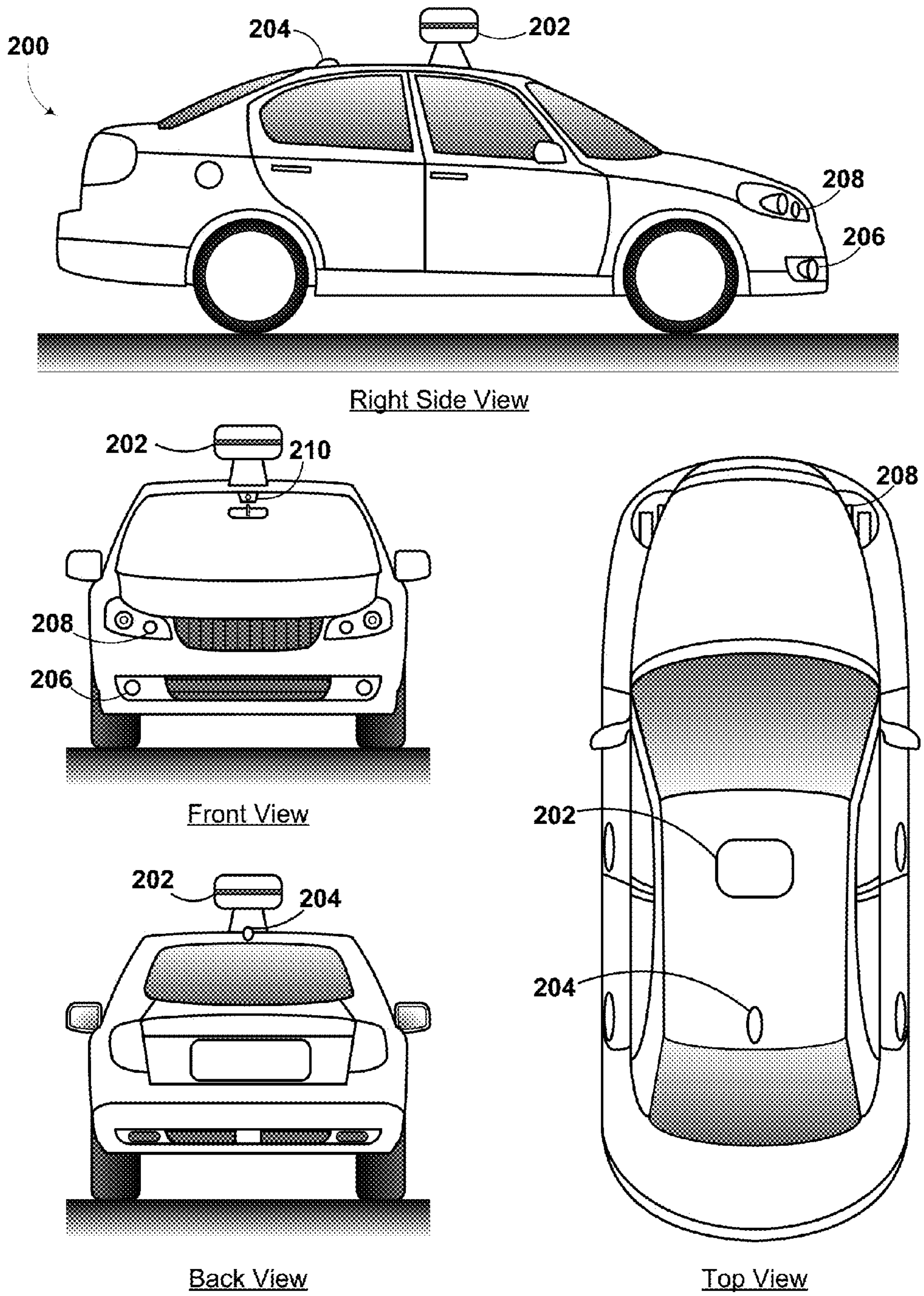
Engine/ Motor 118
Energy Source 119
Transmiss-ion 120
Wheels/ Tires 121
Sensor System 104
Global Positioning System 122
Inertial Measure-ment Unit 124
RADAR Unit 126
Laser Rangefinder / LIDAR Unit 128
Camera 130
Control System 106
Steering Unit 132
Throttle 134
Brake Unit 136
Sensor Fusion Algorithm 138
Computer Vision System 140
Navigation and Pathing System 142
Obstacle Avoidance System 144
Peripherals 108
Wireless Comm. System 146
Touch-screen 148
Microphone 150
Speaker(s) 152
Processor 113
Instructions 115
Data Storage 114
Computer System 112
Power Supply 110
Input/ Output Interface 116

FIG. 1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Front View
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Back View
Top View

FIG. 2

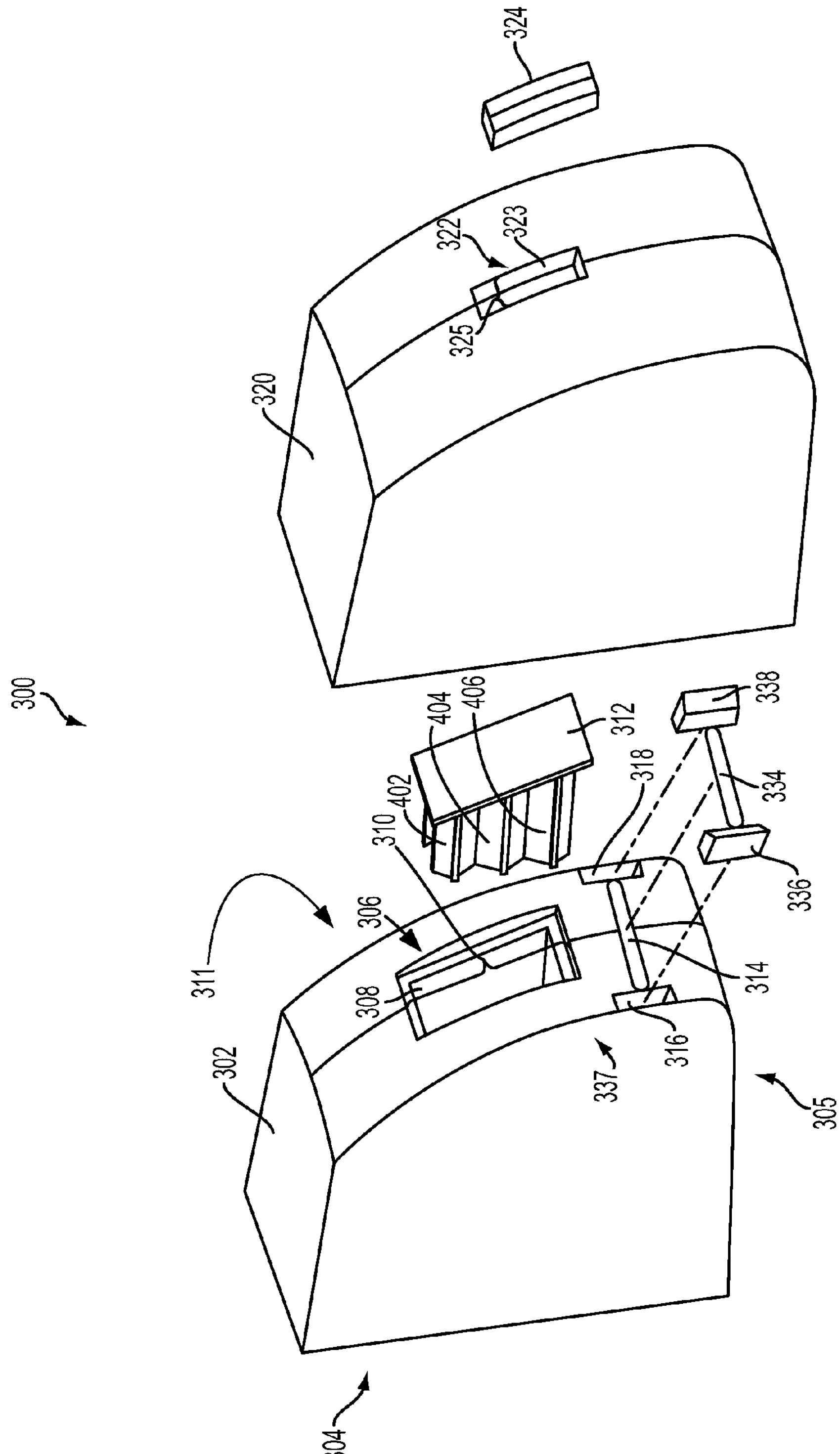
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FIG. 3

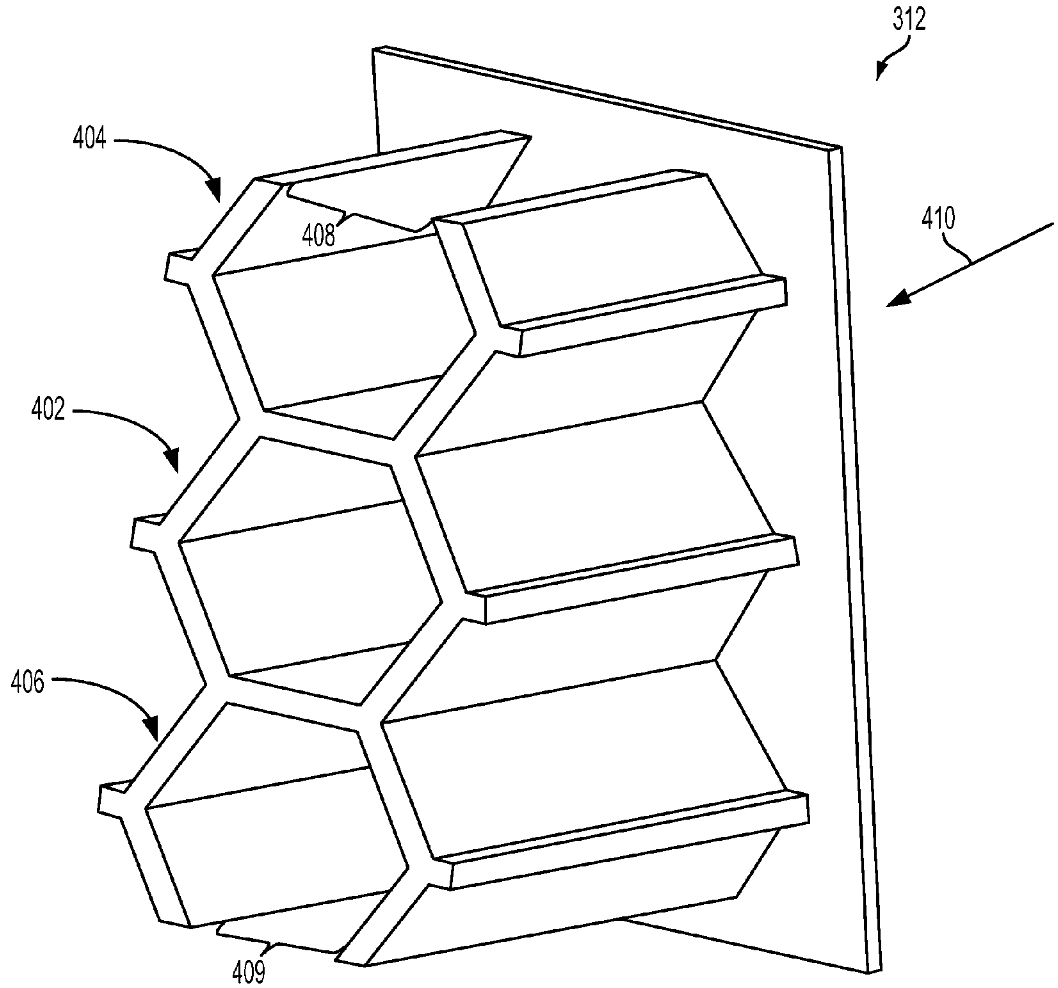

FIG. 4

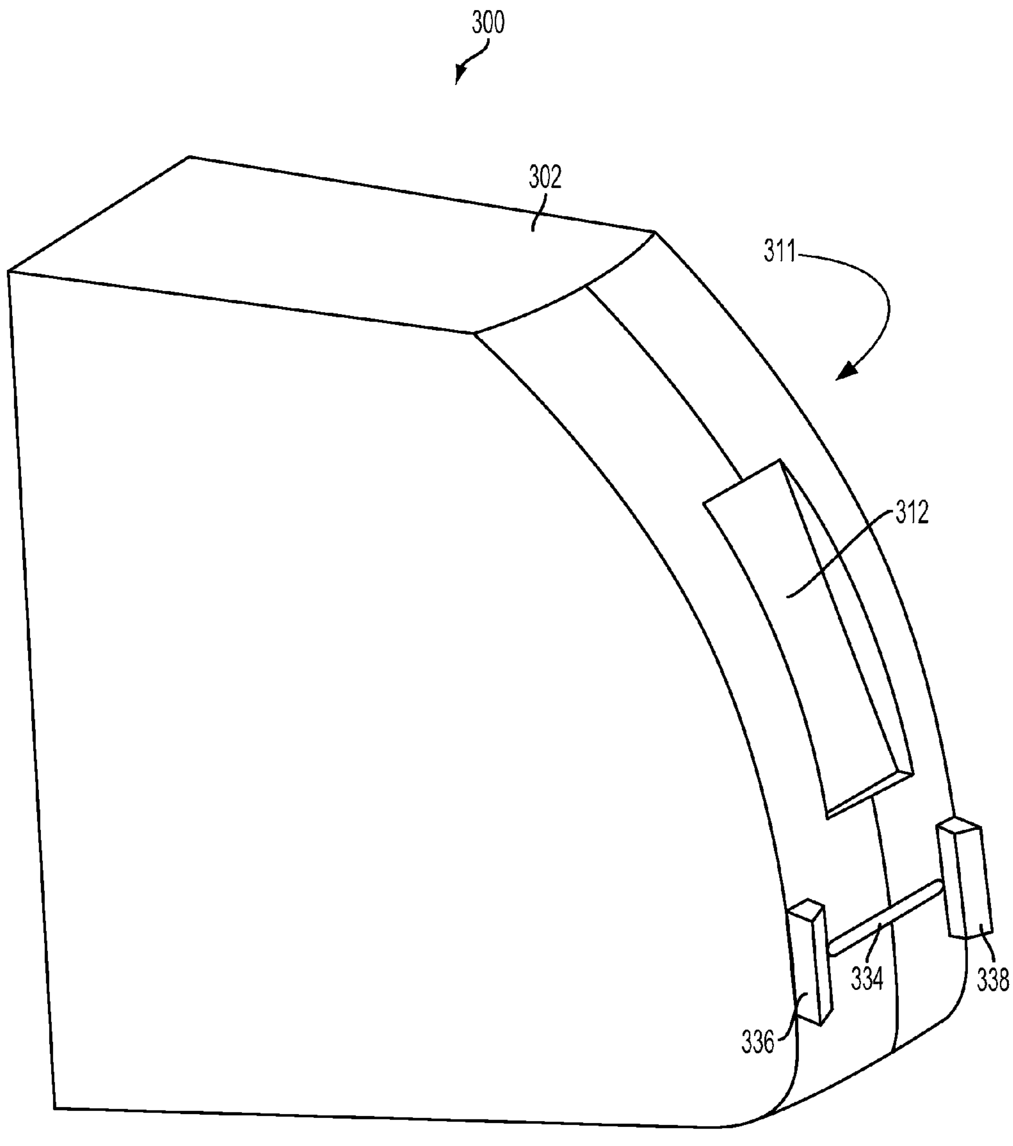

FIG. 5

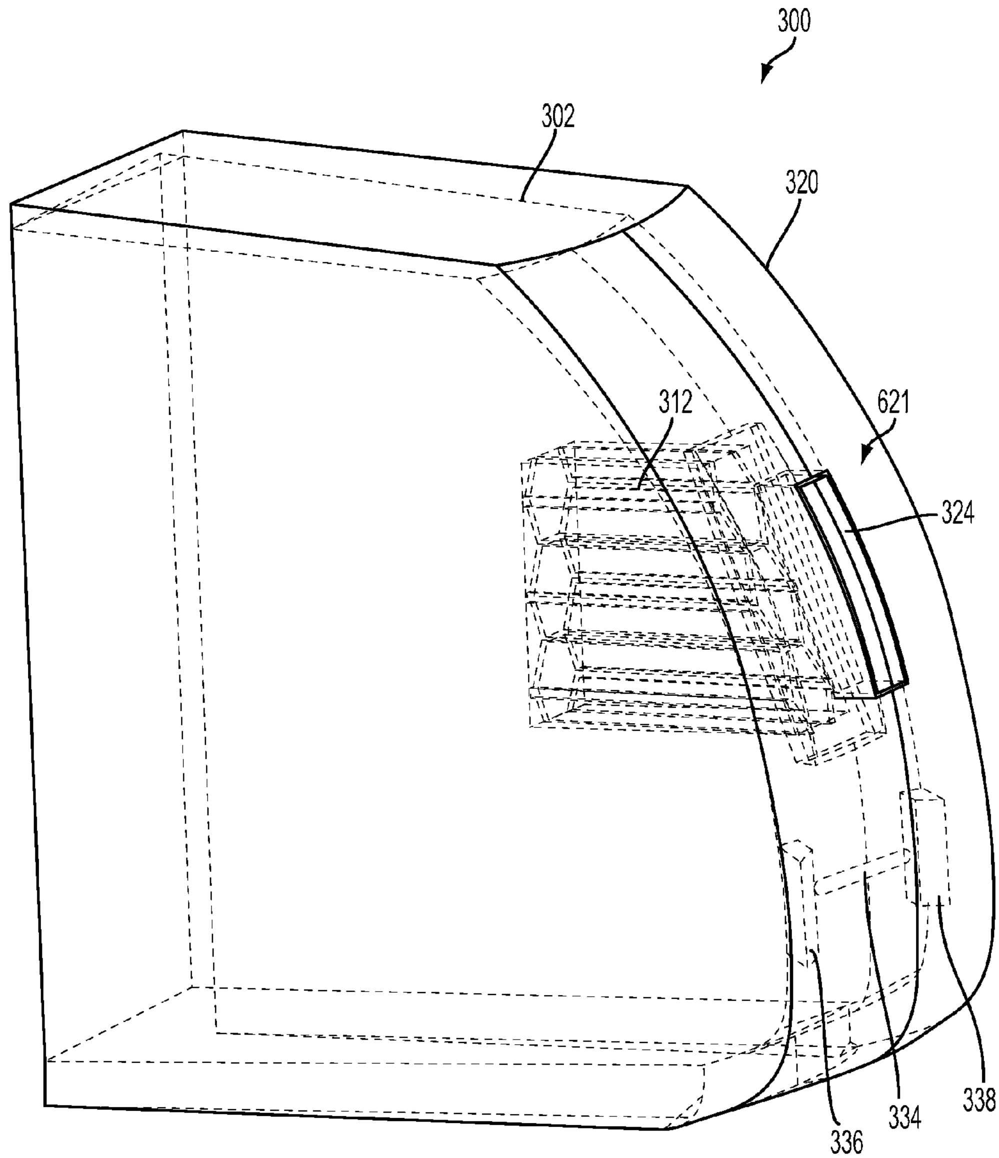

FIG. 6

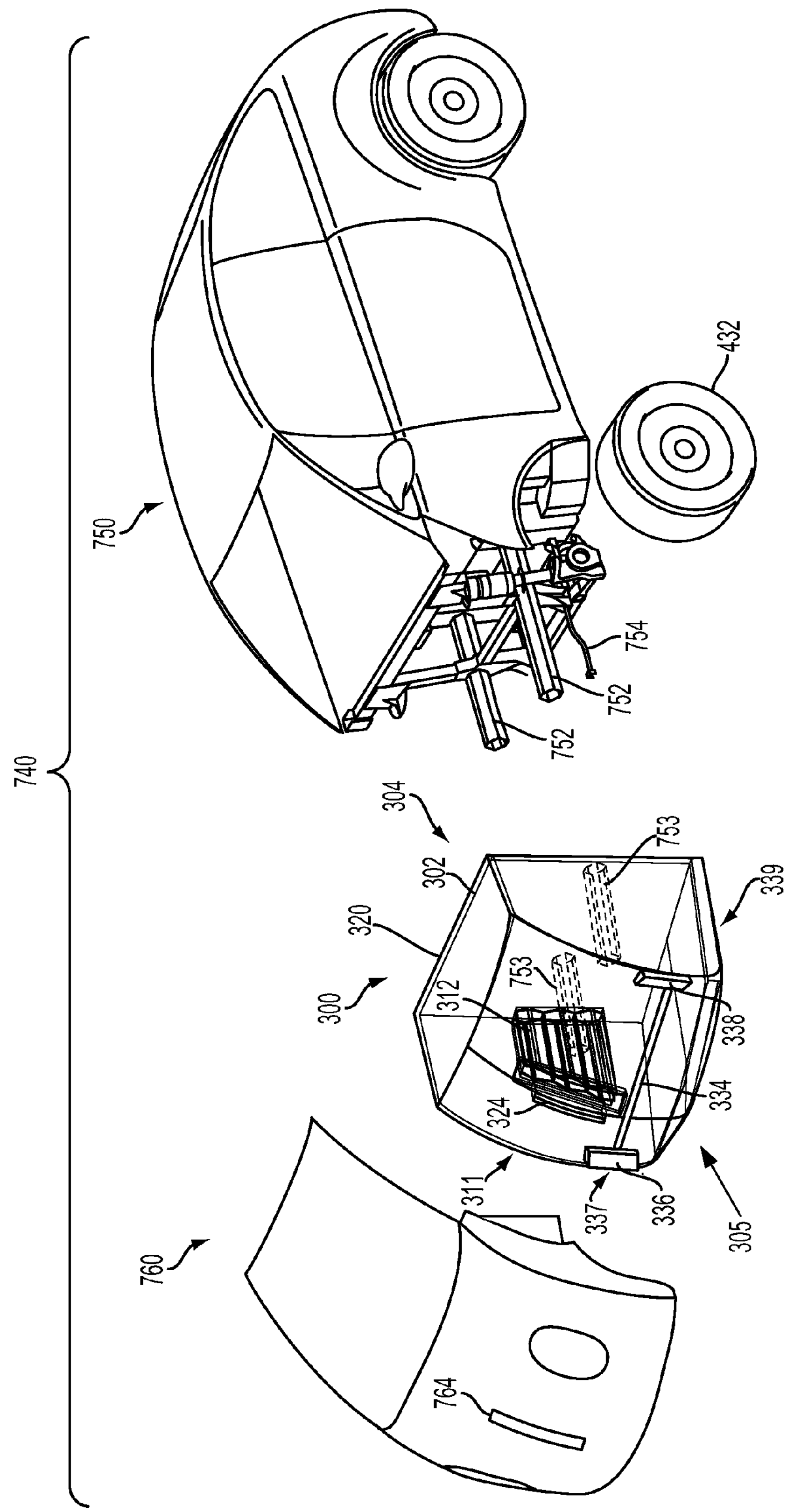
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FIG. 7

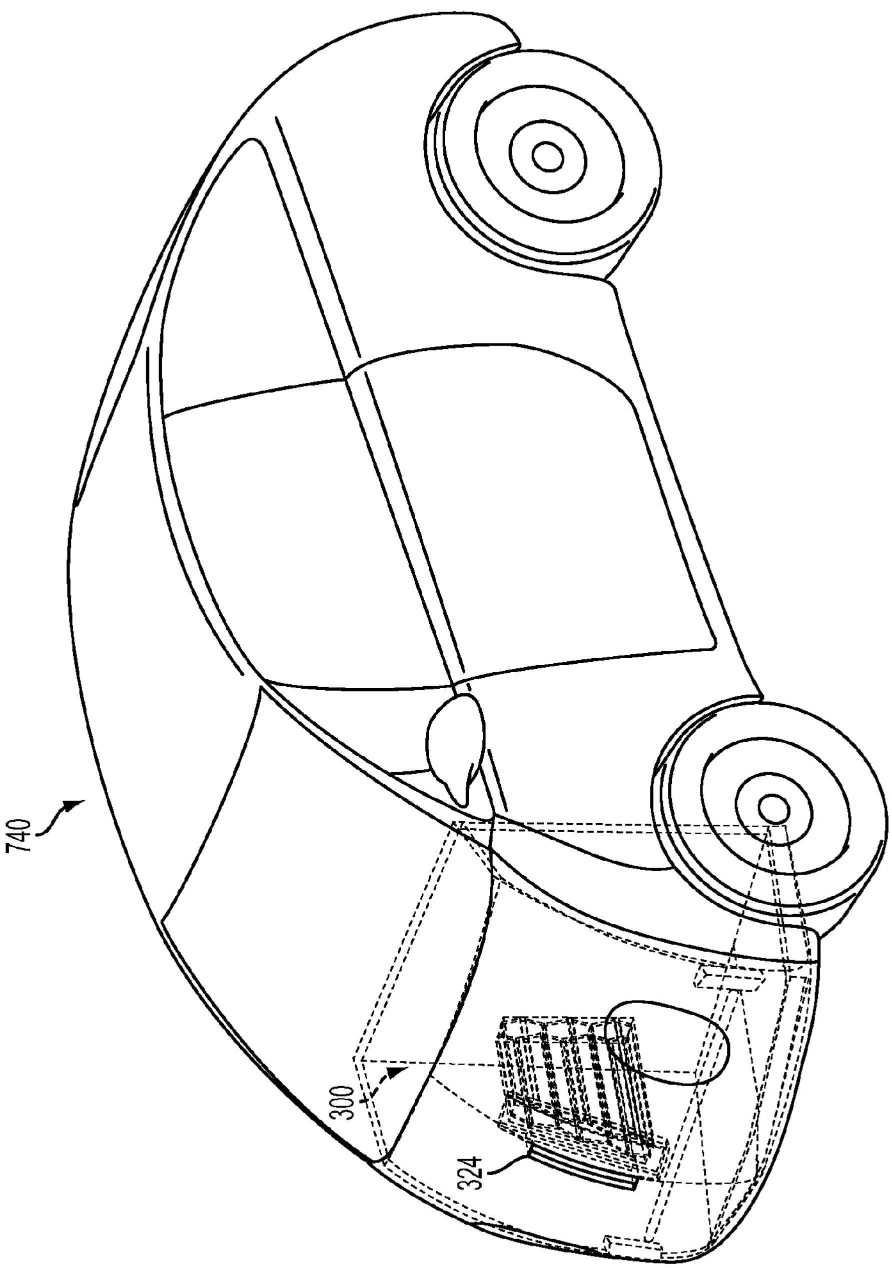

FIG. 8

ENERGY-ABSORBING APPARATUS

BACKGROUND

Unless otherwise indicated herein, the materials described in this section are not prior art to the claims in this application and are not admitted to be prior art by inclusion in this section.

Bumpers and airbags are examples of vehicle systems designed to protect vehicles, vehicle occupants, or other objects. Vehicle bumpers may be installed on a front end and/or a rear end of a vehicle to absorb potential impact forces. Interior airbags may deploy when the vehicle detects contact with another object to prevent injury to occupants of the vehicle.

SUMMARY

In one example, an apparatus includes a casing configured to be coupled to a frame of a vehicle at a first end of the casing. The casing comprises friable foam having a first stiffness. The apparatus further includes a void within the casing defined by (i) an inner wall of the casing and (ii) an opening at a second end of the casing. The apparatus further includes an insert positioned within the void, the insert comprising a material having a second stiffness that is different from the first stiffness.

In another example, a vehicle includes a frame and a passenger compartment coupled to the frame. The vehicle also includes an apparatus that includes a casing coupled to the frame at a first end of the casing so that the casing is adjacent to an exterior of the passenger compartment. The casing comprises friable foam having a first stiffness and a void defined by (i) an inner wall of the casing and (ii) an opening at a second end of the casing. The apparatus further includes an insert positioned within the void of the casing, the insert comprising a material having a second stiffness different from the first stiffness.

In yet another example, an apparatus includes an inner casing configured to be coupled to a frame of a vehicle at a back end of the inner casing so that the inner casing is adjacent to an exterior of a passenger compartment of the vehicle. The inner casing comprises friable foam having a first stiffness. The apparatus further includes a first void within the inner casing defined by (i) an inner wall of the inner casing and (ii) an opening at a front end of the inner casing. The apparatus further includes an insert positioned within the first void, the insert comprising a second friable foam having a second stiffness that is different from the first stiffness and an outer casing configured to be placed over the front end of the inner casing. The apparatus further includes a second void within the outer casing defined by (i) an inner wall of the inner casing and (ii) an opening at a front end of the inner casing.

These as well as other aspects, advantages, and alternatives, will become apparent to those of ordinary skill in the art by reading the following detailed description, with reference where appropriate to the accompanying figures.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1** is a functional block diagram illustrating a vehicle, according to an example embodiment.

FIG. **2** depicts an example vehicle.

FIG. **3** illustrates an exploded view of an example energy-absorbing apparatus.

FIG. **4** illustrates an example insert of an energy-absorbing apparatus.

FIG. **5** illustrates an example inner casing and an example insert of an energy-absorbing apparatus.

FIG. **6** illustrates an assembled view of an example energy-absorbing apparatus.

FIG. **7** illustrates an exploded view of an example vehicle that includes an example energy-absorbing apparatus.

FIG. **8** illustrates an assembled view of an example vehicle that includes an example energy-absorbing apparatus.

DETAILED DESCRIPTION

The following detailed description describes various features and functions of the disclosed systems and methods with reference to the accompanying figures. In the figures, similar symbols identify similar components, unless context dictates otherwise. The illustrative system and method embodiments described herein are not meant to be limiting. It may be readily understood that certain aspects of the disclosed systems and methods can be arranged and combined in a wide variety of different configurations, all of which are contemplated herein.

During operation of a vehicle, it is possible that the vehicle may impact objects, and in some cases it is possible that the vehicle may even impact a person or pedestrian. Therefore, an energy absorbing apparatus coupled to the vehicle is described which aims to reduce or mitigate any potential injury caused by impact with a person or pedestrian.

Within examples, an apparatus may include an inner casing configured to be coupled to a frame of a vehicle (e.g., a car). The inner casing may include a first energy-absorbing material such as a first friable foam having a first stiffness. The apparatus may also include an insert configured to be placed into a void of the inner casing. The insert may include a second energy-absorbing material such as a second energy-absorbing friable foam having a second stiffness that is different from the first stiffness of the inner casing. The insert may be placed into the void and the apparatus may be coupled to the vehicle. The insert may also include one or more structures configured to collapse to absorb an impact force applied to the apparatus during operation of the vehicle. Since the second stiffness of the insert is different from the first stiffness of the inner casing, the insert can be used to change an apparent stiffness of an area of the inner casing containing the insert while allowing some of the inner casing to retain bulk material properties of the first energy-absorbing material.

The apparatus may further include an outer casing that is placed over the inner casing. In various examples, the outer casing may be made up of different materials, including the first and/or second energy-absorbing materials. The outer casing may include a void that is configured to receive a component of the vehicle, such as a sensor or a headlight. The insert positioned within the inner casing may be positioned behind the component so that an impact force applied to the component may be absorbed by the insert.

Depending on a location of the insert within the inner casing and a difference in stiffness between the inner casing and the insert, the apparatus is configured to beneficially guide motion of an object or a person upon impact in an effort to minimize any injury to the person. For example, when the apparatus is coupled to the vehicle, the insert (i.e., the void) could be located at a lower portion of the apparatus near a driving surface and the insert could have an elongated horizontal shape substantially parallel to the driving surface. If the insert is stiffer than the surrounding inner casing, an object (e.g., the person) that contacts the apparatus near the insert may be guided off of the ground and onto a softer area of the inner casing and/or vehicle, thereby mitigating damage or injury to the person or object that may occur if the person or object remains near the driving surface. Or, the apparatus may include wedge-shaped inserts located on opposite sides of the inner casing near a front end of the apparatus. An object (e.g., the person) that contacts the vehicle near one of the wedge-shaped inserts may be redirected toward a softer center region of the apparatus and/or the vehicle, thereby mitigating damage or injury to the person or object. In yet another example, a soft insert may be placed behind a sensor or other component of the vehicle placed near a front end of the vehicle so that the soft insert absorbs an impact force applied to the sensor or component, possibly mitigating damage or injury to the impacted person or object.

Many parameters of the disclosed embodiments allow for variation in properties. For example, hardness, toughness, foam density, foam volume, shape, position, etc., of the various energy-absorbing materials and/or the components of the apparatus may be varied to absorb impact forces at different rates and/or to different extents, or to pivot or guide an impacted object in a particular manner. The embodiments herein may therefore be tuned to specific purposes and applications, depending on the needs of the particular vehicle in question and the particular application.

Additionally, the embodiments disclosed herein may be used on any type of vehicle, including conventional automobiles and automobiles having an autonomous mode of operation. However, the term "vehicle" is to be broadly construed to cover any moving object, including, for instance, a truck, a van, a semi-trailer truck, a motorcycle, a golf cart, an off-road vehicle, a warehouse transport vehicle, or a farm vehicle, as well as a carrier that rides on a track such as a roller coaster, trolley, tram, or train car, among other examples.

Referring now to the figures, FIG. **1** is a functional block diagram illustrating a vehicle **100**, according to an example embodiment. The vehicle **100** could be configured to operate fully or partially in an autonomous mode. For example, the vehicle **100** could be self-controlling while in the autonomous mode, and may be configured to determine a current state of the vehicle **100**, determine an environment of the vehicle **100**, determine a predicted behavior of at least one other vehicle in the environment, determine a confidence level that may correspond to a likelihood of the at least one other vehicle to perform the predicted behavior, and control the vehicle **100** based on the determined information. While in autonomous mode, the vehicle **100** may be configured to operate without human interaction.

The vehicle **100** could include various subsystems such as a propulsion system **102**, a sensor system **104**, a control system **106**, one or more peripherals **108**, as well as a power supply **110**, a computer system **112**, and an input/output interface **116**. The vehicle **100** may include more or fewer subsystems and each subsystem could include multiple elements. Further, each of the subsystems and elements of the vehicle **100** could be interconnected. Thus, one or more of the described functions of the vehicle **100** may be divided into additional functional or physical components, or combined into fewer functional or physical components. In some further examples, additional functional and/or physical components may be added to the examples illustrated by FIG. **1**.

The propulsion system **102** may include components configured to provide motion for the vehicle **100**. In an example embodiment, the propulsion system **102** could include an engine/motor **118**, an energy source **119**, a transmission **120**, and wheels/tires **121**. The engine/motor **118** could be any combination of an internal combustion engine, an electric motor, a steam engine, a Stirling engine, or other types of engines and/or motors. In some embodiments, the engine/motor **118** may be configured to convert the energy source **119** into mechanical energy. In some embodiments, the propulsion system **102** could include multiple types of engines and/or motors. For instance, a gas-electric hybrid car could include a gasoline engine and an electric motor. Other examples are possible.

The energy source **119** could represent a source of energy that may, in full or in part, power the engine/motor **118**. That is, the engine/motor **118** could be configured to convert the energy source **119** into mechanical energy. Examples of energy sources **119** include gasoline, diesel, other petroleum-based fuels, propane, other compressed gas-based fuels, ethanol, solar panels, batteries, and other sources of electrical power. The energy source(s) **119** could additionally or alternatively include any combination of fuel tanks, batteries, capacitors, and/or flywheels. The energy source **119** could also provide energy for other systems of the vehicle **100**.

The transmission **120** could include elements that are configured to transmit mechanical power from the engine/motor **118** to the wheels/tires **121**. To this end, the transmission **120** could include a gearbox, a clutch, a differential, and drive shafts. The transmission **120** could include other elements. The drive shafts could include one or more axles that could be coupled to the one or more wheels/tires **121**.

The wheels/tires **121** of vehicle **100** could be configured in various formats, including a unicycle, a bicycle/motorcycle, a tricycle, or a car/truck four-wheel format. Other wheel/tire geometries are possible, such as those including six or more wheels. Any combination of the wheels/tires **121** of the vehicle **100** may be configured to rotate differentially with respect to other wheels/tires **121**. The wheels/tires **121** could represent at least one wheel that is attached to the transmission **120** and at least one tire coupled to a rim of a wheel that could make contact with a driving surface. The wheels/tires **121** could include any combination of metal and rubber, or another combination of materials.

The sensor system **104** may include a number of sensors configured to sense information about an environment of the vehicle **100**. For example, the sensor system **104** could include a Global Positioning System (GPS) **122**, an inertial measurement unit (IMU) **124**, a RADAR unit **126**, a laser rangefinder/LIDAR unit **128**, and a camera **130**. The sensor system **104** could also include sensors configured to monitor internal systems of the vehicle **100** (e.g., an O_2 monitor, a fuel gauge, or an engine oil pressure gauge). Other sensors are possible as well.

One or more of the sensors included in the sensor system **104** could be configured to be actuated separately and/or collectively in order to modify a position and/or an orientation of the one or more sensors.

The Global Positioning System (GPS) **122** may be any sensor configured to determine a location of the vehicle **100**. To this end, the GPS **122** could include a transceiver configured to provide information regarding the position of the vehicle **100** with respect to the Earth.

The IMU **124** could include any combination of sensors (e.g., accelerometers and gyroscopes) configured to sense position and orientation changes of the vehicle **100** based on inertial acceleration.

The RADAR unit **126** may represent a system that utilizes radio signals to sense objects within the environment of the vehicle **100**. In some embodiments, in addition to sensing the objects, the RADAR unit **126** may additionally be configured to sense the speed and/or direction of motion of the objects.

Similarly, the laser rangefinder/LIDAR unit **128** may be any sensor configured to sense objects in the environment of the vehicle **100** by using lasers. In an example embodiment, the laser rangefinder/LIDAR unit **128** could include one or more laser sources, a laser scanner, and one or more detectors, among other system components. The laser rangefinder/LIDAR unit **128** could be configured to operate in a coherent (e.g., using heterodyne detection) or an incoherent detection mode.

The camera **130** could include one or more devices configured to capture a plurality of images of the environment of the vehicle **100**. The camera **130** could be configured to captures still frames and/or continuous video.

The control system **106** may be configured to control operation of the vehicle **100** and its components. Accordingly, the control system **106** could include various elements including a steering unit **132**, a throttle **134**, a brake unit **136**, a sensor fusion algorithm **138**, a computer vision system **140**, a navigation and pathing system **142**, and an obstacle avoidance system **144**.

The steering unit **132** could represent any combination of mechanisms that may be configured to adjust a direction of motion of the vehicle **100**. For example, a steering wheel or steering column may be mechanically coupled to the wheels/tires **121** and turning the steering wheel or steering column may cause the wheels/tires **121** to change the direction of motion of the vehicle **100**.

The throttle **134** could be configured to control, for instance, the operating speed of the engine/motor **118** and, in turn, control the speed of the vehicle **100**. For example, the throttle **134** may be configured to increase or decrease a rate of energy conversion of the energy source **119** that is converted to mechanical energy by the engine/motor **118**.

The brake unit **136** could include any combination of mechanisms configured to decelerate the vehicle **100**. The brake unit **136** could use disc or drum brakes that use friction to slow rotation of the wheels/tires **121**. In other embodiments, the brake unit **136** could convert kinetic energy of the wheels/tires **121** to electric current. The brake unit **136** may take other forms as well.

The sensor fusion algorithm **138** may be an algorithm configured to accept data from the sensor system **104** as an input. (The sensor fusion algorithm **138** may be data representing the sensor fusion algorithm stored in the data storage **114**.) The input data may include, for example, data representing information sensed by the sensors of the sensor system **104**. The sensor fusion algorithm **138** could include, for instance, a Kalman filter, a Bayesian network, or another algorithm. The sensor fusion algorithm **138** could further provide various assessments based on the data from the sensor system **104**. In an example embodiment, the assessments could include evaluations of individual objects and/or features in the environment of vehicle **100**, an evaluation of a particular situation, or evaluations of possible impacts based on the particular situation. Other assessments are possible.

The computer vision system **140** may be any system configured to process and analyze images captured by the camera **130** in order to identify objects or features in the environment of vehicle **100**, including traffic signals, roadway boundaries, and obstacles. The computer vision system **140** could use an object recognition algorithm, a Structure From Motion (SFM) algorithm, video tracking, and other computer vision techniques. In some embodiments, the computer vision system **140** could be additionally configured to map an environment, track objects, or estimate the speed of objects.

The navigation and pathing system **142** may be any system configured to determine a driving path for the vehicle **100**. The navigation and pathing system **142** may additionally be configured to update the driving path dynamically while the vehicle **100** is in operation. In some embodiments, the navigation and pathing system **142** could be configured to incorporate data from the sensor fusion algorithm **138**, the GPS **122**, and one or more predetermined maps so as to determine the driving path for vehicle **100**.

The obstacle avoidance system **144** could represent a control system configured to identify, evaluate, and avoid or otherwise negotiate potential obstacles in the environment of the vehicle **100**.

The control system **106** may additionally or alternatively include components other than those shown and described.

Peripherals **108** may be configured to receive input data or provide outputs, including to or from external sensors, other vehicles, and other computer systems. For example, peripherals **108** could include a wireless communication system **146**, a touchscreen **148**, a microphone **150**, and a speaker **152**.

In one example, the wireless communication system **146** could be configured to wirelessly communicate with one or more devices directly or via a communication network. For example, the wireless communication system **146** could use 3G cellular communication, such as CDMA, EVDO, GSM/GPRS, or 4G cellular communication, such as WiMAX or LTE. Alternatively, the wireless communication system **146** could communicate with a wireless local area network (WLAN), for example, using WiFi. In some embodiments, the wireless communication system **146** could communicate directly with a device, for example, using an infrared link, Bluetooth, or ZigBee. Other wireless protocols, such as various vehicular communication systems, are possible within the context of the disclosure. For example, the wireless communication system **146** could include one or more dedicated short range communications (DSRC) devices that could include public and/or private data communications between vehicles and/or roadside stations.

In an example embodiment, the touchscreen **148** may be configured to display information, including information describing a state of the vehicle **100**. The input/output interface **116** could also be configured to accept input from the touchscreen **148**. The touchscreen **148** may be configured to sense a position and/or a movement of a finger via capacitive sensing, resistance sensing, or a surface acoustic wave process, among other possibilities. The touchscreen **148** may be capable of sensing finger movement in a direction parallel or planar to the touchscreen surface, or in a direction normal to the touchscreen surface, and may also be capable of sensing a level of pressure applied to the surface of the touchscreen **148**. The touchscreen **148** may be formed of one or more translucent or transparent insulating layers and one or more translucent or transparent conducting layers. The touchscreen **148** may take other forms as well.

The microphone **150** may be configured to detect sound waves (e.g., a voice command) and convert the sound waves into audio signals for use by the computer system **112**. Similarly, the speakers **152** may be configured to receive audio signals and convert the audio signals into sound waves.

The power supply **110** may provide power to various components of the vehicle **100** and could represent, for example, a rechargeable lithium-ion or lead-acid battery. In some embodiments, one or more banks of such batteries could be configured to provide electrical power to the vehicle **100**. Other power supply components and configurations are possible. In some embodiments, the power supply **110** and the energy source **119** could be implemented together, as in some all-electric cars.

Many or all of the functions of the vehicle **100** could be controlled by the computer system **112**. The computer system **112** may include at least one processor **113** (which could include at least one microprocessor) that executes the instructions **115** stored in a non-transitory computer readable medium, such as the data storage **114**. The computer system **112** may also represent a plurality of processors or computing devices that may serve to control individual components or subsystems of the vehicle **100** in a distributed fashion.

In some embodiments, the data storage **114** may contain the instructions **115** (e.g., program logic) executable by the processor **113** to execute various functions of vehicle **100**, including those described above in connection with FIG. **1**. The data storage **114** may contain additional instructions as well, including instructions to transmit data to, receive data from, interact with, and/or control one or more of the propulsion system **102**, the sensor system **104**, the control system **106**, and the peripherals **108**.

In addition to the instructions **115**, the data storage **114** may store data such as roadway maps, path information, among other information. Such information may be used by the vehicle **100** and the computer system **112** during the operation of the vehicle **100** in the autonomous, semi-autonomous, and/or manual modes.

The computer system **112** may control the function of the vehicle **100** based on inputs received from various subsystems (e.g., the propulsion system **102**, the sensor system **104**, and the control system **106**), as well as from the input/output interface **116**. For example, the computer system **112** may utilize input from the control system **106** in order to control the steering unit **132** to avoid an obstacle detected by the sensor system **104** and the obstacle avoidance system **144**. In an example embodiment, the computer system **112** could be configured to provide control over many aspects of the vehicle **100** and its subsystems.

The vehicle **100** may include an input/output interface **116** for providing information for output or receiving input from the peripherals **108**. The input/output interface **116** could control or enable control of content and/or a layout of interactive images that could be displayed on the touchscreen **148**. Further, the input/output interface **116** could include one or more input/output devices within the set of peripherals **108**, such as the wireless communication system **146**, the touchscreen **148**, the microphone **150**, and the speaker **152**.

Although FIG. **1** shows various components of the vehicle **100**, i.e., the wireless communication system **146**, the computer system **112**, the data storage **114**, and the input/output interface **116**, as being integrated into the vehicle **100**, one or more of these components could be mounted or associated separately from the vehicle **100**. For example, the data storage **114** could, in part or in full, exist separate from the vehicle **100**. Thus, the vehicle **100** could be provided in the form of device elements that may be located separately or together. The device elements that make up the vehicle **100** could be communicatively coupled together in a wired and/or wireless fashion.

FIG. **2** depicts an example vehicle **200** that could be similar to the vehicle **100** described in FIG. **1**. Although the vehicle **200** is illustrated in FIG. **2** as a car, other embodiments are possible. For instance, the vehicle **200** could represent a truck, a van, a semi-trailer truck, a motorcycle, a golf cart, an off-road vehicle, or a farm vehicle, among other examples.

In some embodiments, the vehicle **200** could include a sensor unit **202**, a wireless communication system **204**, a LIDAR unit **206**, a laser rangefinder unit **208**, and a camera **210**. The elements of the vehicle **200** could include some or all of the elements described as part of the vehicle **100**, depicted in FIG. **1**.

The sensor unit **202** could include one or more different sensors configured to capture information about an environment of the vehicle **200**. For example, the sensor unit **202** could include any combination of cameras, RADARs, LIDARs, range finders, and acoustic sensors. Other types of sensors are possible. In an example embodiment, the sensor unit **202** could include one or more movable mounts that could be configured to adjust the orientation of one or more sensors in the sensor unit **202**. In one embodiment, the movable mount could include a rotating platform that could scan sensors so as to obtain information from many directions around the vehicle **200**. In another embodiment, the movable mount of the sensor unit **202** could be moveable in a scanning fashion within a particular range of angles and/or azimuths. The sensor unit **202** could be mounted atop a roof of the vehicle **200**, for instance, however other mounting locations are possible. Additionally, the sensors of the sensor unit **202** could be distributed in different locations and need not be in a single location. Some possible sensor types and mounting locations include the LIDAR unit **206** and the laser rangefinder unit **208**, as depicted in FIG. **2**. Furthermore, each sensor of the sensor unit **202** could be configured to be moved or scanned independently of other sensors of the sensor unit **202**.

The wireless communication system **204** could be located on a roof of the vehicle **200** as depicted in FIG. **2**. Alternatively, the wireless communication system **204** could be located, fully or in part, elsewhere. The wireless communication system **204** may include wireless transmitters and receivers that could be configured to communicate with devices external or internal to the vehicle **200**. Specifically, the wireless communication system **204** could include transceivers configured to communicate with other vehicles and/or computing devices, for instance, in a vehicular communication system or a roadway station. Examples of such vehicular communication systems include dedicated short range communications (DSRC), radio frequency identification (RFID), and other communication standards directed towards intelligent transport systems.

The camera **210** may be any camera (e.g., a still camera, a video camera, etc.) configured to capture a plurality of images of the environment of the vehicle **200**. To this end, the camera **210** may be configured to detect visible light, or may be configured to detect light from other portions of an electromagnetic spectrum, such as infrared or ultraviolet light. Other types of cameras are possible as well.

The camera **210** may be a two-dimensional detector, or may have a three-dimensional spatial range. In some embodiments, the camera **210** may be, for example, a range detector configured to generate a two-dimensional image indicating a distance from the camera **210** to a number of points in the environment. To this end, the camera **210** may use one or more range detecting techniques. For example, the camera **210** may use a structured light technique in which the vehicle **200** illuminates an object in the environment with a predetermined light pattern, such as a grid or checkerboard pattern and uses the camera **210** to detect a reflection of the predetermined light pattern from the object. Based on distortions in the reflected light pattern, the vehicle **200** may determine the distance to the points on the object. The predetermined light pattern may comprise infrared light, or light of another wavelength. As another example, the camera **210** may use a laser scanning technique in which the vehicle **200** emits a laser and scans across a number of points on an object in the environment. While scanning the object, the vehicle **200** may use the camera **210** to detect a reflection of the laser from various points of the object. Based on a length of time it takes the laser to reflect from the object at various points, the vehicle **200** may determine the distance to the points on the object. As yet another example, the camera **210** may use a time-of-flight technique in which the vehicle **200** emits a light pulse and uses the camera **210** to detect a reflection of the light pulse from an object at a number of points on the object. In particular, the camera **210** may include a number of pixels, and respective pixels may detect the reflection of the light pulse from a point on the object. Based on a length of time it takes the light pulse to reflect from the object at various points, the vehicle **200** may determine the distance to the points on the object. The light pulse may be a laser pulse. Other range detecting techniques are possible as well, including stereo triangulation, sheet-of-light triangulation, interferometry, and coded aperture techniques, among others. The camera **210** may take other forms as well.

The camera **210** could be mounted inside a front windshield of the vehicle **200**. Specifically, as illustrated in FIG. **2**, the camera **210** could capture images from a forward-looking view with respect to the vehicle **200**. Other mounting locations and viewing angles of camera **210** are possible, either inside or outside the vehicle **200**.

The camera **210** could have associated optics that could be configured to provide an adjustable field of view. Further, the camera **210** could be mounted to vehicle **200** with a movable mount that could be configured to vary a pointing angle of the camera **210**.

The vehicle **200** may include an energy-absorbing apparatus coupled to a frame of the vehicle **200**. The energy-absorbing apparatus may be configured to absorb an impact force applied by an object during a collision, for example. The frame of the vehicle may include a rigid metal skeleton that supports various structures of the vehicle **200**, but in other examples the frame may include any structure of the vehicle suitable for coupling to the energy-absorbing apparatus.

FIG. **3** illustrates an exploded view of an example energy-absorbing apparatus **300**. FIG. **3** includes an inner casing **302** further including a first end **304** (i.e., a back end), a bottom end **305**, a first void **306**, an inner wall **308**, an opening **310**, a second end **311** (i.e., a front end), a third void **316**, a fourth void **318**, and a fifth void **314**. FIG. **3** also includes a first insert **312**, a horizontally elongated insert **334**, a first wedge-shaped insert **336**, a second wedge-shaped insert **338**, an outer casing **320**, a second void **322**, and an object **324**.

The inner casing **302** may comprise a first energy-absorbing material or first friable foam having a first stiffness, such as closed cell foam, open cell foam, polyurethane foam, XPS foam, polystyrene, phenolic, memory foam, flower foam, or any other material suitable for absorbing an impact force. A friable foam may include any foam material configured to crumble, disintegrate or otherwise be reduced to smaller pieces when impacted with a reasonably small impact force. Other types of energy-absorbing materials are possible as well such as sponges, rubbers, aluminium honeycomb, etc. The inner casing **302** may be configured to be coupled to a frame of a vehicle **740** (shown in FIGS. **7** and **8**) via various attachment means (e.g., tie-down straps, fasteners, or adhesives) at the first end **304** of the inner casing **302**. The first end **304** may be shaped and/or contoured to fit snugly against the frame or another portion of the vehicle **740**. Alternatively or additionally, the bottom end **305** of the inner casing **302** may be configured to be coupled to the frame of the vehicle **740** and/or to fit snugly against the frame or another portion of the vehicle **740**. The inner casing **302** coupling to the frame of the vehicle **740** may include directly coupling so that the inner casing **302** contacts the frame of the vehicle **740**, or indirectly coupling so that the inner casing **302** is attached to the frame via other structural components of the vehicle **740**. In various examples, the frame of the vehicle **740** may include a single integrated framework for attaching various vehicle components, but in other examples, the frame could include any structural component of the vehicle **740**.

At the second end **311**, the inner casing **302** includes the first void **306** defined by the inner wall **308** and the opening **310**. In FIG. **3**, the first void **306** is depicted as having a rectangular shape, but other shapes are possible. The first void **306** may be configured to receive the first insert **312**. As shown in FIG. **3**, the first end **304** may be opposite the second end **311** that includes the opening **310**.

The first insert **312** may be made up of a second energy-absorbing material or second friable foam having a second stiffness that is different from the first stiffness of the inner casing **302**. The first insert **312** may also be made up of closed cell foam, open cell foam, polyurethane foam, XPS foam, polystyrene, phenolic, memory foam, flower foam, sponges, rubbers, aluminium honeycomb, or any other material suitable for absorbing an impact force. The first insert **312** may be inserted into the first void **306** through the opening **310**. Once positioned within the first void **306**, the first insert **312** may or may not protrude outside the first void **306**, depending on relative sizes of the first insert **312** and the first void **306**. The first insert **312** may be adhesively coupled to the inner wall **308**, fit snugly within the first void **306**, fit loosely within the first void **306**, or otherwise be coupled to the inner casing **302** within the first void **306**.

In various examples, the apparatus **300** may include one or more of the inserts **312**, **334**, **336**, and **338** placed into respective voids of the inner casing **302**, with the respective voids being defined by respective inner walls and openings. In other examples, the inserts **312**, **334**, **336**, and **338** may be coupled to the inner casing **302** without being placed into a void of the inner casing **302**. That is, the inserts **312**, **334**, **336**, and/or **338** may be mounted directly to an exterior surface of the inner casing **302**.

The horizontally elongated insert **334** may form a "kicker bar" configured to direct objects that impact the horizontally elongated insert **334** upward into a potentially softer region of the vehicle, such as a central region of the inner casing **302** that includes the first insert **312**. For example, the inner casing **302** may be coupled to the frame of the vehicle so that a front portion (e.g., the second end **311**) of the casing forms part of a front end of the vehicle. The horizontally elongated insert **334** may be located along a bottom region of the front portion of the inner casing **302**, as shown in FIG. **3**. Here, a stiffness of the horizontally elongated insert **334** may be greater than the stiffness of the inner casing **302**, so that an object that impacts the inner casing **302** near the horizontally elongated insert **334** may be moved off of a driving surface and into a softer region of the vehicle such as the central region of the inner casing **302** that includes the first insert **312**.

The first wedge-shaped insert **336** maybe located on a first side **337** of a front portion (e.g., the second end **311**) of the inner casing **302** and the second wedge-shaped insert **338** be located on a second side **339** of the front portion of the inner casing **302**. As shown in FIG. **3**, the first side **337** of the front portion of the inner casing **302** may be opposite the second side **339** of the front portion of the inner casing **302** (see FIG. **7**). The first wedge-shaped insert **336** and the second wedge-shaped insert **338** may be composed of an energy-absorbing material or friable foam having a stiffness that differs from the stiffness of the inner casing **302**. The respective stiffness of the inserts **336** and **338** may be greater than the stiffness of the inner casing **302** so that an object that impacts the inner casing **302** near the first wedge-shaped insert **336** or the second wedge-shaped insert **338** is directed toward a softer region of the inner casing **302** such as the central region that includes the first insert **312**. In other examples, the first wedge-shaped insert **336** and the second wedge-shaped insert **338** may have shapes other than a wedge shape.

Although in FIG. **3** the fifth void **314**, the third void **316**, and the fourth void **318** are depicted as being separate voids or cavities within the inner casing **302**, in other examples the voids **314**, **316**, and **318** may be a continuous void or cavity within the inner casing **302** and the inserts **334**, **336**, **338** may be formed as one continuous insert.

The (optional) outer casing **320** may be made of any material suitable for absorbing an impact force, including any of the materials that make up other portions of the apparatus **300**. The outer casing **320** may be placed over the second end **311** of the inner casing **302**. The outer casing **320** may include a second void **322** configured to receive an object **324**. The second void **322** may be defined by an inner wall **323** and an opening **325** of the outer casing **320**. In one example, the first insert **312** has a lesser stiffness than the inner casing **302**, and when the outer casing **320** is placed over the inner casing **302**, the first insert **312** is positioned behind the second void **322** and the object **324**. The object **324** could be a vehicle component or sensor such as a headlight or a LIDAR sensor, and the first insert **312** could be positioned and configured to absorb an impact force applied to the object **324** and/or the outer casing **320**.

It should be noted that in some examples, the apparatus **300** may include several layers of casings. For example, an intermediate casing (not shown) that is similar to the inner casing **302** and/or the outer casing **320** may be placed over the inner casing **302**, and the outer casing **320** may be placed over the intermediate casing. In this way, several layers of "nested" casings may be used. Inserts such as the first insert **312**, the horizontally elongated insert **334**, the first wedge-shaped insert **336**, and the second wedge-shaped insert **338** may be placed into various voids of any of the inner casing, the intermediate casing, or the outer casing.

FIG. **4** illustrates an example insert **312** of an energy-absorbing apparatus. The insert **312** includes a first structure **402**, a second structure **404**, a third structure **406**, an open end **408**, and an open end **409**.

The first structure **402** may include a three-dimensional structure made up of a friable foam material, such as a closed honeycomb or hexagonal structure depicted in FIG. **4**. As the insert **312** receives the impact force **410**, the first structure **402** may be configured to collapse, deform, or disintegrate to absorb the impact force **410**. The first structure **402** may share one or more surfaces with the second structure **404** and/or the third structure **406**.

The second structure **404** may include a three-dimensional structure made up of a friable foam material, such as an open honeycomb or hexagonal structure depicted in FIG. **4**. As the insert **312** receives the impact force **410**, the second structure **404** may be configured to collapse, deform, or disintegrate to absorb the impact force **410**. The second structure **404** may share one or more surfaces with the first structure **402**. The second structure **404** may include an open end **408** as shown in FIG. **4**.

The third structure **406** may include a three-dimensional structure made up of a friable foam material, such as an open honeycomb or hexagonal structure depicted in FIG. **4**. As the insert **312** receives the impact force **410**, the third structure **406** may be configured to collapse, deform, or disintegrate to absorb the impact force **410**. In another example, the third structure **406** may include a closed hexagonal or honeycomb structure similar to the first structure **402**. The third structure **406** may include an open end **409** as shown in FIG. **4**.

One or more of the structures **402**, **404**, and **406** may be mutually substantially identical or be substantial mirror-images. For example, in FIG. **4** the second structure **404** is a mirror-image of the third structure **406**.

FIG. **5** illustrates an example inner casing **302** and an example first insert **312** of an energy-absorbing apparatus **300**.

As shown in FIG. **5**, the first insert **312** may be located within a central region of a front portion (e.g., the second end **311**) of the inner casing **302**. A stiffness of the inner casing **302** may be greater than a stiffness of the first insert **312** so that damage to objects that impact the vehicle **740** and/or the inner casing **302** near the central region of the front portion of the inner casing **302** is mitigated.

When the first insert **312** is placed into a void of the inner casing **302**, a front surface of the first insert **312** may be recessed from a front surface of the inner casing **302**. In other examples, the front surface of the first insert **312** may extend past the front surface of the inner casing **302** or be flush with the front surface of the inner casing **302**.

FIG. **6** illustrates an assembled view of an example energy-absorbing apparatus **300**. FIG. **6** includes an inner casing **302**, a first insert **312**, an outer casing **320**, front surface **621**, an object **324**, a horizontally elongated insert **334**, a first wedge-shaped insert **336**, and a second wedge-shaped insert **338**.

As depicted in FIG. **6**, the outer casing **320** is placed over a front end of the inner casing **302**. The outer casing **320** may have a front surface **621** configured to couple to a front shell or fascia of a vehicle **740**. For example, the object **324** may be a sensor of the vehicle **740** placed within a void of the outer casing **320** so that a front surface of the sensor is flush with or slightly recessed or slightly extended from a front surface **621** of the outer casing **320**. For instance, the sensor may be a radar sensor and placement within the void of the outer casing **320** may allow the sensor to be sufficiently exposed to surroundings to collect data regarding the surroundings. In a situation in which the first insert **312** is less stiff than the surrounding inner casing **302**, the placement of the object **324** within the void of the outer casing **320** in front of the first insert **312** may mitigate damage caused to objects that are impacted by the object **324** during a collision.

The inserts **334**, **336**, and **338** may be positioned behind the outer casing **320** to perform various functions. For example, the horizontally elongated insert **334** may be stiffer than the surrounding inner casing **302** and/or the outer casing **320**. Objects that impact the apparatus **300** near the horizontally elongated insert **334** may be directed up off of a driving surface and into a central area of the apparatus **300** that includes the first insert **312**, which may be less stiff than the surrounding inner casing **302**. By directing an impacted object up into the central region of the apparatus **300** that includes the first insert **312**, damage to the impacted object may be mitigated.

The wedge-shaped inserts **336** and **338** may be positioned behind the outer casing **320** to perform various functions. For example, the wedge-shaped inserts **336** and **338** may be stiffer than the surrounding inner casing **302** and/or the outer casing **320**. Objects that impact the apparatus **300** near the first wedge-shaped insert **336** or second wedge-shaped insert **338** may be directed toward the central area of the apparatus **300** that includes the first insert **312**, which may be less stiff than the surrounding inner casing **302**. Or, the object may directed by the first wedge-shaped insert **336** or the second wedge-shaped insert **338** toward the horizontally elongated insert **334**. Then the horizontally elongated insert **334** may direct the impacted object toward the central region of the apparatus **300**. By directing an object into the central region that includes the first insert **312**, damage to the impacted object may be mitigated.

FIG. 7 illustrates an exploded view of an example vehicle **740** that includes an example energy-absorbing apparatus **300**. The vehicle **740** may comprise a front shell **760**, the apparatus **300**, a passenger compartment **750**, a frame **752**, a component/sensor cable **754**, and an opening **764**. The apparatus **300** may include a first end **304** and an object **324**.

The first end **304** of the apparatus **300** may be configured to be coupled to a frame or another structural portion of the vehicle **740**. For example, the first end **304** may be a back end of an inner casing **302** of the apparatus **300**, and may include receiving holes **753** for receiving the frame **752**. As an example, the frame **752** could be adhesively coupled to the apparatus **300** at the receiving holes **753**. Other methods of coupling the apparatus **300** to the frame of the vehicle **740** are possible.

The object **324** may be a sensor or another component of the vehicle **740** that is configured to be electrically coupled to other portions of the vehicle **740** (e.g., the processor **113** of FIG. **1**). The object **324** may be electrically coupled to the vehicle via the component/sensor cable **754**. When the object **324** is placed into a void of an outer casing of the apparatus **300** as shown in FIG. **7**, a front surface of the object **324** may be configured to be flush with the opening **764** of the front shell **760**. Alternatively, the object **324** could be recessed or extended with respect to the opening **764** when the front shell **760** is coupled to the apparatus **300**. The front shell **760** may be contoured or shaped to fit snugly over a front end of the apparatus **300**.

FIG. **8** illustrates an assembled view of an example vehicle **740** that includes an example energy-absorbing apparatus **300**. As shown, a front shell is placed over a front end of the apparatus **300** such that an object **324** is exposed. The object **324** (e.g., a component or sensor) may be placed within a void of an outer casing of the apparatus **300** such that a front surface of the object **324** is flush with the front shell of the vehicle **740**. In situations where the object **324** is a sensor, the depicted position of the sensor may allow the sensor to collect data regarding surroundings of the vehicle. As shown in FIG. **8**, the inner casing and/or outer casing of the apparatus **300** is adjacent to an exterior of the passenger compartment of the vehicle **740**.

It should be understood that arrangements described herein are for purposes of example only. As such, those skilled in the art will appreciate that other arrangements and other elements (e.g. machines, interfaces, functions, orders, and groupings of functions, etc.) can be used instead, and some elements may be omitted altogether according to the desired results. Further, many of the elements that are described are functional entities that may be implemented as discrete or distributed components or in conjunction with other components, in any suitable combination and location, or other structural elements described as independent structures may be combined.

While various aspects and embodiments have been disclosed herein, other aspects and embodiments will be apparent to those skilled in the art. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope being indicated by the following claims, along with the full scope of equivalents to which such claims are entitled. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting.

What is claimed is:

1. An apparatus comprising:

an inner casing configured to be coupled to a frame of a vehicle at a first end of the inner casing, wherein the inner casing is made of a first friable foam having a first stiffness;

a first void within the inner casing defined by (i) an inner wall of the inner casing and (ii) an opening at a second end of the inner casing; and

a first insert made of a second friable foam, wherein the first insert is positioned within the first void, and wherein the second friable foam has a second stiffness that is different from the first stiffness.

2. The apparatus of claim **1**, wherein the first end of the inner casing is opposite the second end of the inner casing.

3. The apparatus of claim **1**, wherein the first insert comprises a first structure configured to collapse as the first insert absorbs an impact force.

4. The apparatus of claim **3**, wherein the first structure has a hexagonal shape.

5. The apparatus of claim **4**, further comprising a second structure that has a hexagonal shape with an open end.

6. The apparatus of claim **1**, further comprising:

an outer casing placed over the second end of the inner casing; and

a second void within the outer casing configured to receive an object.

7. The apparatus of claim **6**, wherein the second stiffness is less than the first stiffness and the first insert is positioned behind the second void.

8. The apparatus of claim **1**, further comprising:

a horizontally elongated insert that is located at the second end of the inner casing below the first insert, wherein a stiffness of the horizontally elongated insert is greater than the first stiffness, and wherein the first stiffness is greater than the second stiffness.

9. The apparatus of claim **8**, further comprising:

a first wedge-shaped insert located on a first side of the second end of the inner casing, wherein the first wedge-shaped insert has a stiffness that is greater than the first stiffness; and

a second wedge-shaped insert located on a second side of the second end of the inner casing, wherein the second side is opposite the first side, and wherein the second wedge-shaped insert has a stiffness that is greater than the first stiffness.

10. The apparatus of claim **1**, further comprising:

a first wedge-shaped insert located on a first side of the second end of the inner casing, wherein the first wedge-shaped insert has a stiffness that is greater than the first stiffness; and

a second wedge-shaped insert located on a second side of the second end of the inner casing, wherein the second side is opposite the first side, wherein the second wedge-shaped insert has a stiffness that is greater than the first stiffness, and wherein the first stiffness is greater than the second stiffness.

11. The apparatus of claim **6**, wherein the object comprises a sensor.

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